ORGANIZING A SYSTEM OF ACTIONS WITH RANDOM ALTERNATION OF SIGNALS, SEARCH AND CHOICE OF ACTIONS

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In our previously described experiments we showed that in forming a system of four actions (pressing keys arranged in a row on a panel) in the case of a random sequence of two equally probable signals, each of which is connected with two specific actions, man applies a method for devising rules for choosing a decision. In the process of learning such a problem all the test subjects (9 persons) first divided their actions into groups corresponding to signals, then established working rules within each group for repetitions of signals, and finally set up rules of transitions between actions relating to different groups when the signals changed. The experiments also showed that people combine transitions in response to the same sequence of signals to form a general working rule for the given signal combination. /97

In learning the problem, each action of the test subject was a repetition of the action of the experimenter, who, by triggering a signal, simultaneously "opened up" the key on the test subject's panel that corresponded to the predetermined program. Thus, a specific program of actions was imposed on the test subjects and they had to learn to reproduce it. In view of these experimental conditions, the test subjects were not able to display all the capabilities available to man in organizing his activity.

It is well known, for example, that people can choose a specific order of actions from several possible ones and can constantly maintain this order. Andreas and Miller [4] presented test subjects with the problem of working through a word maze, which required them to reproduce several times a given phrase, connecting the letters, which were scattered over the page, with a line, always in the same order. As the training improved, the test subjects began to choose a specific route and the probability that the previous route would be repeated at the tenth trial increased to 1.00. There are data testifying to the fact that not infrequently different people choose the same methods of action. In Liberman's experiments [5] the test subjects were asked to predict how three balls would hit three squares under the condition that each ball would hit each square with equal probability. The majority of the test subjects made the same assumptions. Of 27 possible ways the balls might hit, only 2 were predicted with the greatest frequency: either the three balls would hit one square, or each of the three balls would hit each of the three squares.

Thus, man can choose some method of solving a problem, probably the one most suitable for him, and can constantly stick to it. If one and the same problem is presented to a group of test subjects, the majority will make the same choices.

Continuing our research on the study of complex forms of stereotypic human activity, we decided to find out how test subjects would form a system of actions in the case of a random sequence of two signals if they are given the possibility of choosing the next action from several possible ones.

For this purpose the test subjects were asked to solve the same problem as /98
in the preceding experiments, but not with 4, but 12 keys, arranged 4 to a row on the panel. The free choice of one of several possible actions was ensured by connecting the keys of each column (three each) in such a way that the response would be correct regardless which of them the test subject pressed. The test subjects were not told anything about this feature of the panel.

In this experiment the human problem was considerably more complicated. In addition to the fact that the test subjects had to organize a system consisting of a larger number of actions (pressing 12 keys), they themselves had to choose specific transistions between actions. On the other hand, the structure of the panel permitted them to reduce the number of actions to four, if they guessed the way the keys were connected.

Thus, the test subjects would have had to reproduce only part of the experimental program in changing over from one column of keys to the next, and they chose the keys and fixed the transitions between them according to their own discretion.

The problem of the given experiment was to study how does man form a system of actions when he is capable of freely choosing specific transitions between individual actions and how, under the conditions of the given experiment, can people reduce the number of their actions.

METHOD

We gave a detailed description of the experimental method in the preceding communication. Here we will dwell only on those details which were added to the method especially for the given investigation.

The Test Subjects were eleven persons of both sexes, ranging in age from 16 to 30, volunteers, not having participated in the experiments of the preceding investigation.

The Experimental Setup consisted of two panels. Twelve keys of the inverted "N" type were arranged four to a row on the test subject's panel. Four keys of the same type were arranged on the experimenter's panel; each of them was connected to three keys on the panel of the test subject (Fig. 1, A). With one of the keys the experimenter turns on a signal on the test subject's panel and simultaneously "opens" the column of keys that is connected to this key. The test subject can extinguish the signal by pressing any of the three keys of the "open" column.

The program was made up according to the same principle as in the preceding experiments. A diagram of the rules by which the given program was set up is shown in Fig. 1, B. The working rules for each possible signal combination /99
were as follows:

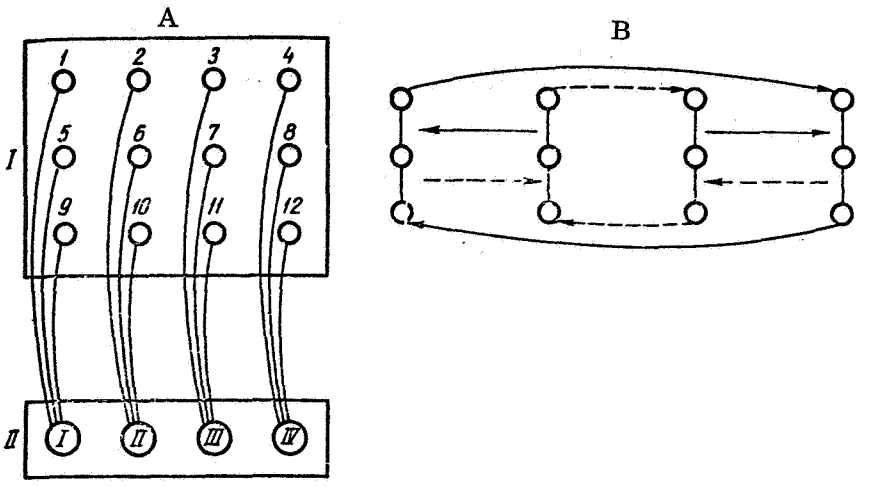

Figure 1. Diagram of the Experimental Arrangement (A) and of the Rules for the Experimental Program (B).

I—Test Subject's Panel; II—Experimenter's Panel. Circles - Keys of the Panel; Solid Arrows - Transitions on the Red Signal; Broken Arrows - Transitions on the Green Signal.

1) when the green signal was repeated several times in succession, it was required to go in turn from one middle group of keys to the keys of the next middle group;

2) when the red signal was repeated several times in succession, it was required to go in turn from one outer group of keys to the keys of the next outer group;

3) when the red signal was followed by a green signal, it was required to go from the outer groups of keys to the keys of the adjacent middle group;

4) when the green signal was followed by a red signal, it was required to go from the middle groups of keys to the keys of the adjacent outer group.

The instruction issued to the test subjects before beginning the experiment, the investigational procedure, the indicators and the learning criteria were the same as in the preceding experiments.

Experimental Results

The experiments demonstrated that all the test subjects were able to organize their actions into a system that corresponded to the experimental program. Since the methodological approach we used permitted a free choice to be made of the specific transitions between keys, it proved possible to combine the results of the test subjects and to consider them as mean data for the group as a whole. An analysis of the data was begun by examining the responses of each test subject. In doing so we singled out two forms of responses — general and exact. /100

Among the general responses we classified those cases when the test subjects completed actions incident to the prevailing signal. For example, in response to the red signal they pressed the keys of the outer groups, and on the green signal, the keys of the middle groups. Consequently, the general responses contained both correct actions, when the test subjects chose keys of the group which corresponded to the rules of transitions between actions, as well as incorrect actions, when they chose keys of another group.

An increase in frequency of the general responses should have indicated that the test subjects found rules which governed the relations between groups of actions and each of the signals. Considered to be exact responses were only correct actions. An increase in exact actions was taken to indicate how rapidly the test subjects discovered the rules governing transitions between concrete actions. Comparison of the results of analyzing the response actions made it possible to divide the test subjects into two groups which differed sharply from each other in the way the general and exact responses increased. The data are presented in Figs. 2 and 3. Plotted on the axis of abscissas is the learning level in % of the total number of trials; on the ordinate axis is the relative frequency of responses from the total number of actions of the test subjects, taken to be unity. The curves in the figures show the relations between the general and exact responses for the test subjects of the first group (mean data of seven people) and of the second group (mean data of 4 test subjects). As is evident from Fig. 2, A, the relative frequency of the general responses from the test subjects of the first group was /101
0.92 already at the end of the second period; at the end of the third period it was close to 1.00. The exact responses of these test subjects increased more slowly, and despite the fact that all the test subjects derived the learning criterion (threefold correct execution of all the moves stipulated by the program in accordance with the arrows on the graph), the mean frequency of exact responses in the last period was 0.94. Such a relationship between the general and exact responses indicates that the test subjects first divided their actions into sets attendant upon each of the signals, and then established transitions between individual actions. Shown in Fig. 2, B, are both types of responses to repetition of the same signal, and in Fig. 2, C, the same responses, but to a change in signals. When signals were repeated, the principal increase of both the general and exact responses was observed at the start of learning, and in the third period their frequency had already exceeded 0.90, reaching, respectively, 1.00 and 0.99 at the end of the last period. When signals were changed, the exact responses lagged considerably behind the general ones and their frequency at the end of learning was 0.89.

In essence, the data of the 1st group of test subjects did not differ from the results obtained in our preceding experiments, when they formed a system of four actions.

No difference was observed between the general and exact responses of the 2nd group of test subjects. Regardless of whether we examined the relationship between responses as a whole (Fig. 3, A) or separated the cases of signal repetition (Fig. 3, B) or signal change (Fig. 3, C), both types of responses increased slowly and their relative frequencies at the end of learning were lower than in the test subjects of the first group. The data obtained from the second group of test subjects reveal that they did not divide their actions into sets relative to different /102
signals, but applied another strategy to find rules for the choice of a decision.

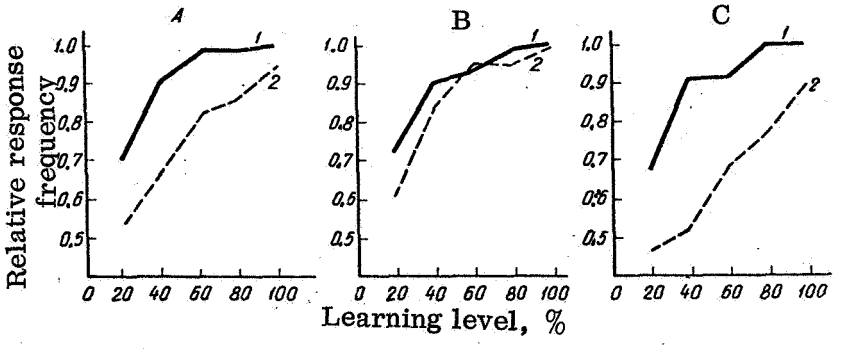

Figure 2. Relations Between the General and Exact Responses for the Test Subjects of the First Group.

A—Of all the Responses as a Whole; B—With Signal Repetitions; C—With Change of Signals. 1—General Responses; 2—Exact Responses.

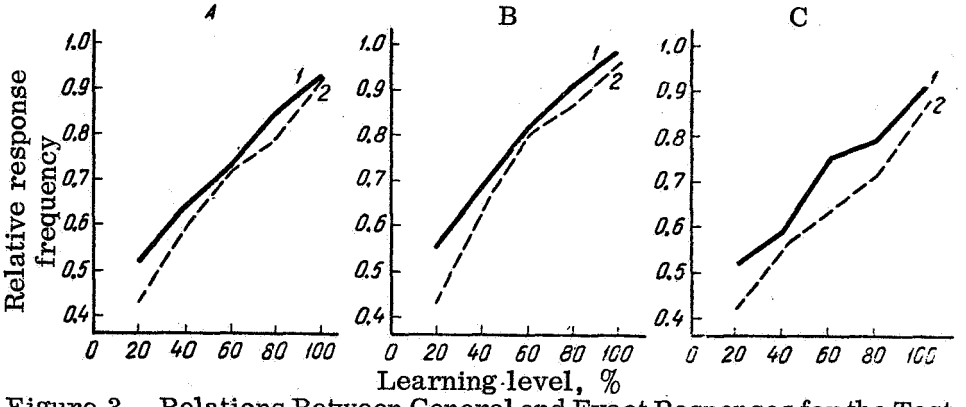

Figure 3. Relations Between General and Exact Responses for the Test Subjects of the Second Group. Notation the Same as in Fig. 2.

At the same time as we analyzed the responses of the test subjects we considered how many keys they use to organize a system of actions. Even in this case substantial differences were found between individual test subjects. The data are presented in Table 1, where the following points were entered for each test subject: 1) number of keys he used at different learning levels (from 5 to 100%); 2) learning speed (number of trials required to discover the learning criterion); and 3) membership in the 1st or 2nd group, depending upon the nature of the growth in general and exact responses. As evident from the table, three people immediately began organizing a system of four actions. Six people began to learn by using 12 (in one case 10) keys and reduced the number of keys to 4 at various learning levels.

In addition we attempted to compare the learning speed with the number of keys used. If we determine the speed at which the test subjects occupying the first five positions in the table learned, that is, those people who used only four keys at the very start of learning, it turns out that one test subject needed 1400 trials to achieve the learning criterion, another only 80. The learning speeds of the other three people were 200, 200 and 355 trials. If these data are compared

TABLE 1. Number of Keys Used By the Test Subjects to Organize a System of Actions

Test subjects	Group	Learning speed (no. of trials)	Learning level, in % of the total number of trials																			
			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
G. M.	1st	200	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
L. Shch.	2nd	355	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
V. R.	1st	200	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
A. N.	2nd	1400	12	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
T. F.	1st	80	10	10	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
V. Ch.	2nd	700	12	12	12	12	12	12	12	12	4	4	4	4	4	4	4	4	4	4	4	4
V. G.	1st	600	12	12	10	10	10	10	10	10	10	10	10	10	11	10	4	4	4	4	4	4
V. B.	2nd	500	12	12	12	12	12	12	12	12	12	12	12	12	8	8	4	4	4	4	4	4
A. Sh.	2nd	170	12	12	12	12	12	12	12	12	12	12	12	12	12	12	4	4	4	4	4	4
L. T.	1st	245	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Ya. N.	2nd	1700	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12

with the learning speeds of the test subjects occupying the last two positions in the table, it turns out that one man learned in 245 trials, the other in 1700. Both of them formed a system of 12 actions. These data do not permit us to conclude that the number of keys used has any effect on the learning rate.

The last question we examined was the relationship between the number of keys used and between the general and exact responses. In the given case such a relationship was observed, since all the test subjects who changed to 4 keys at the very initial learning levels belonged to the first group insofar as the relations between general and exact responses are concerned. All the people who belonged to the second group either reduced the number of keys at a considerably later period or continued using all the keys of the panel to the very end of learning.

When we attempted to compare the learning rate of the first and second groups, it was found that there were test subjects in both groups who rapidly organized a system of actions and also slowly (80, 200, 600 and 1400 trials in the first group; 170, 500 and 1700 trials in the second group). Despite this fact, the mean learning rate and the mean error for the first group was 363 ± 199, and 767 ± 329 /104 trials for the second group. We cannot judge the statistical reliability of these differences in view of the small number of groups, but it can be assumed that the learning rate depends on how the test subjects acquire rules for choosing a decision.

Analysis of the data showed that if the test subjects are given some freedom in choosing actions, they apply different methods of finding rules for the choice of a decision. Therefore it was necessary to examine two aspects: what rules do the test subjects use in organizing a system of actions (do they discover the same rules we used to set up the experimental program, or do they formulate their own rules) and attempt to find out what method of search for rules in choosing a decision the test subjects of the second group applied?

In our first communication we described in detail how, on the basis of differences in rate of evolving individual transitions, it was found that people combined transitions carried out in response to one and the same sequence of actions into a working rule for each possible signal combination.

In the present paper we used this method to determine whether the test subjects discovered the rules of transitions we used as a basis in setting up our experimental program? For this purpose we determined the speed with which transitions between individual sets of keys were involved and compared the differences between transitions combined by a common signal combination (separately for each group of test subjects). The reliability of the differences was verified by the t criterion. The differences were considered to be reliable for $P \leqslant 0.01$. These calculations did not reveal reliable differences in the rate of evolution between individual transitions for the test subjects of either the first or second groups ($0.2 > P > 0.1$).

Consequently, when people had a free choice of transitions between actions, they did not find working rules for each signal combination, but formed a system of actions by another method.

The analysis we made of the data showed that in the process of learning most test subjects reduced the number of their actions to four. Having the possibility of choosing any of the three keys of each group, the test subjects were able to

establish transitions between actions according to their own discretion, using other rules. Therefore we decided to find out the keys on which test subjects fix their choice. It was found that toward the end of the learning cycle three test subjects began to use the four keys of the upper row, and two chose the keys of the middle row. The other four fixed their choice on keys of different rows. When we examined the paths which they transversed in moving the arm from the keys of one row to those of another row, it was found that the test subjects described, by their motions, so to speak, figures over the surface of the panel. Graphic illustrations of the motions of the arm by a human being are shown in Fig. 4, which contains a schematic representation of the panel and the keys arranged on it. Arm motions executed on the red signal are shown by a solid arrow and on the green signal by a broken arrow. Shown in the figure are the motions of the four test subjects who fixed their choice on four keys located in different rows (I, II, III, IV). As is evident from the figure, in transferring their arms from key to key they described closed symmetrical figures over the surface of the panel. The data of test subject T-a, who organized a system of 12 actions, are shown in Fig. 4, V(a, b, c, d, e, f, g, h). Despite the large number of transitions between various keys, completely symmetrical actions of the test subject were observed in this case also.

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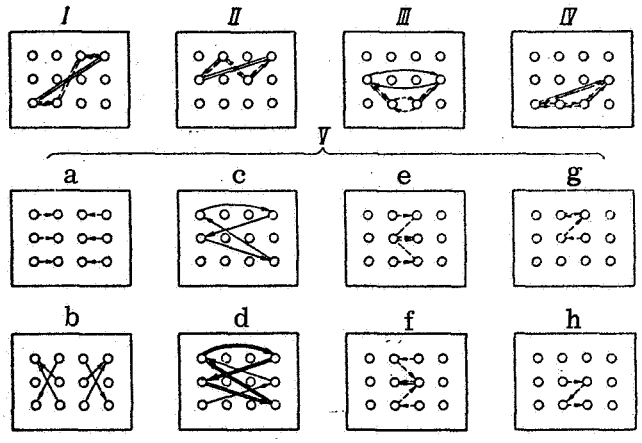

Figure 4. Schematic Illustrations of the Motions of the Human Arm: The Blocks Represent the Panel, the Circles Inverted "N" Type Keys. The Solid Arrows Show the Direction of Arm Motion to the Red Signal and the Broken Arrows, to the Green Signal. I, II, III, IV, V (a, b, c, d, e, f, g, h) are the Motions of the Arms of 5 Test Subjects Over a Two-Dimensional Space.

These data permit us to state that when test subjects have a free choice of keys on the panel, they form a system of actions by creating closed symmetrical figures over the surface of the panel and, in moving from one set of keys to the next, they describe a sort of figure by the motion of their arms.

CONCLUSION

In this investigation our problem was to determine: 1) how man forms a system of actions when he has a free choice of one of three possible actions; and 2) can people in the course of learning reduce the number of actions if the working panel contains an excess number of keys.

/106

In the preceding experiments it was demonstrated that when people formulated a system of four actions, during the learning process they discovered the rules by which the experimental program was set up. In the experiments whose results we considered in the present article, the test subjects had to organize a system of

4-12 actions under the condition that the test subjects were presented with a free choice not only of their own actions (choice of any three keys of each set), but also of the transitions between actions (transistion from the keys of one group to those of another).

The experiments showed that under the conditions of the given experiment, all the people organized a system of actions. In analyzing the material, however, it was found that one group of test subjects (7 people) was able to only partially find rules for choosing a decision. These people divided the entire set of their actions into two groups and established relations between each group and the pertinent signal. But they were not able to combine the various actions performed in response to the same signal combination and to find transition rules for these actions. After dividing the actions into groups corresponding to signals, these test subjects began to use another strategy to find the correct solution. The second group of test subjects (4 people), from the very start of the learning process, did not divide their actions into blocks in response to each of the signals and formed a system of actions by another method

Since in these experiments the actions of the test subjects could be executed in two-dimensional space and not in a straight line (as was the case when a system of four actions was organized), it was possible to assume that the test subjects found points of focus on the surface of the panel and formed the system of actions as two-dimensional figures. In the investigations of our laboratory [3] it was shown that in forming a sequence of actions a human being combines individual motor acts into blocks, and if in executing a block of actions his hand describes some sort of closed symmetrical figure on the surface of the panel, this block is easier to acquire than blocks of actions which do not form a pattern.

If the test subject found a point belonging to the outline of the pattern, he filled in the rest of the outline by choosing the next points.

When we analyzed how people transferred their arms when moving from key to key and travel sketches of these paths, it turned out that in forming a system of actions in two-dimensional space all the test subjects put together completely symmetrical geometric figures on the surface of the panel.

Hence it can be concluded that the dominant factor in organizing a system of actions in two-dimensional space is how to choose actions which will ensure the construction of a figure in space. Therefore, in our experiments the test subjects did not discover working rules for each possible signal combination, but /107
used a method whereby they found points on the surface of the panel which would allow them to organize a symmetrical figure. Having found such points, they established transitions which gave shape to the figure.

The second aspect dealt with the capability of people to reduce the number of their actions. During the learning process the majority of test subjects reduced the number of keys they used to four.

The literature contains data testifying that in the execution of motor tasks man tends to reduce the number of motions, retaining only the most essential actions. Arana and Sokolov [1, 2] studied in man the tactile perception of letter imprints or the discovery of checkers in various area elements of the working

space. The authors found that people first felt their way systematically over the entire surface on which the letter or checker was displayed and, as they gained experience, began to check only those spots which might be informative.

Under our experimental conditions, when two successive signals changed positions in a random sequence, it was difficult to find out how people changed over from a large number of actions to a smaller number. Therefore it can be said that a feature inherent in man is the reduction of the volume of actions in organizing a system. The question as to how he reduces the number of actions in solving logical problems connected with the finding of rules for making a choice of decisions deserves special attention and may be the subject of a special investigation.

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